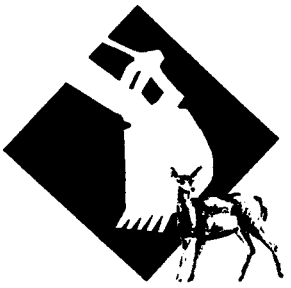


ABANDONED COAL MINE LANDS RESEARCH PROGRAM

FIFTH-SEMI ANNUAL PROJECT REVIEW SEMINAR

UNIVERSITY OF WYOMING
LARAMIE, WYOMING

OCTOBER 8, 1993

The seminar series is sponsored jointly by the University of Wyoming, Office of Research and the Abandoned Mine Lands Program of the Wyoming Department of Environmental Quality.

STRATEGIES FOR ESTABLISHMENT OF BIG SAGEBRUSH (Artemisia tridentata spp. wyomingensis) ON WYOMING MINED LANDS

G.E. SCHUMAN, D.T. BOOTH, AND J.R. COCKRELL

Strategies for Establishment of Big Sagebrush (Artemisia tridentata ssp. wyomingensis) on Wyoming Mined Lands.

G.E. Schuman, D.T. Booth, and J.R. Cockrell

Introduction

Wyoming big sagebrush is one of the most widely distributed and adapted shrub species in Wyoming and the region. Although considerable debate has surrounded its value, and the need for re-establishment during mined land reclamation, the fact remains that reclamationists are often advised and sometimes required to restore sagebrush to mined lands at densities that approximate predisturbance conditions. In light of this, methods for establishment of big sagebrush are an important area of revegetation research and technology development. Sagebrush is well adapted and persistent when mature, but establishment from seed has proven difficult. Problems include low seedling vigor, seedling inability to compete with herbaceous species, poor seed quality and/or ecotypic adaptation, inability of agronomic seeding methods to meet seed microsite requirements, and effects of altered soil conditions on establishment of the effective vesicular-arbuscular mycorrhizal (VAM) associations that are important to sagebrush seedling survival.

A research study was initiated in January 1991, to test several cultural approaches so as to define effective strategies for obtaining stands of big sagebrush on mined lands. Specific objectives include:

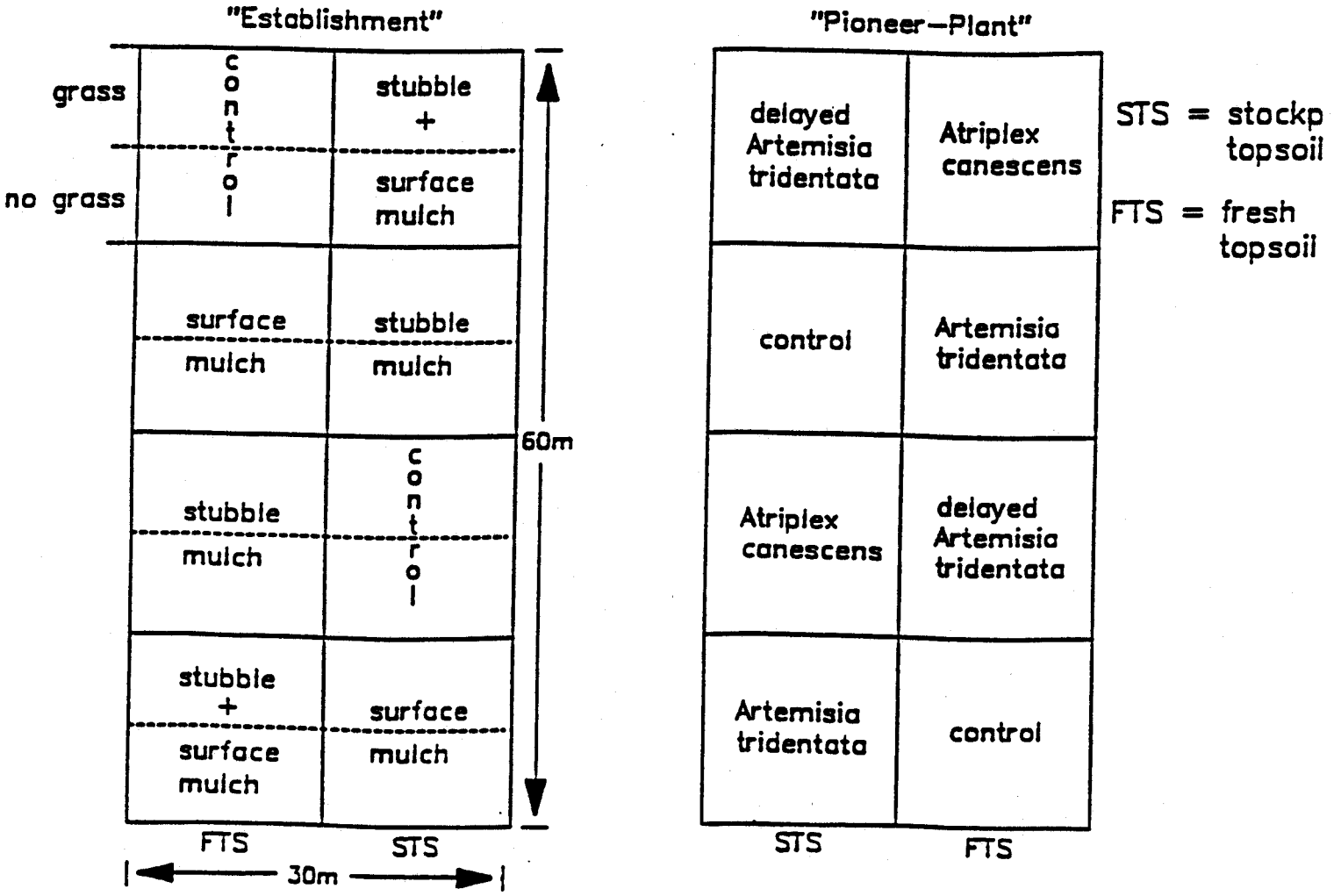
1. Efficacy of direct-applied topsoil for enhanced sagebrush stand establishment through effects of VAM and the topsoil as a seed source.
2. The value of a stubble mulch crop of annual grain for sagebrush establishment through effects on snow catchment and microsite modification.
3. The usefulness of surficially applied hay/straw mulch in improving sagebrush establishment through seed/seedling protection and microsite modification.
4. The effect of competition from concurrently seeded herbaceous species on establishment of sagebrush, and
5. The value of seeding fourwing saltbush as a pioneer species for enhancing soil biological properties leading to the natural recruitment of sagebrush.

The research will allow evaluation of the primary questions and interactive effects among treatments in a manner to suggest an optimal combination of methods to enhance sagebrush revegetation. It is anticipated that application of technology developed from this project will directly benefit entities involved in western mined land reclamation.

Project Description

This project is composed of two compatible studies that are being conducted simultaneously. These are identified as the "Establishment Study" and "Pioneer Plant Study" (Figure 1). The Establishment Study will test techniques for sagebrush establishment, and will be fully completed during the three year term of this project. The Pioneer Plant Study will be a longer-term investigation of plant succession manipulation intended to enhance

Figure 1. Field plot diagram of a representative block of the "Establishment" and fourwing saltbush "Pioneer Plant" studies; each block has been replicated three times with main treatments (Table 1) randomly assigned within the split-plot experimental design.



sagebrush establishment. Initial results of the pioneer Study will be available by year three of the present project, but several additional years of monitoring will be necessary for full evaluation of treatment effects.

Establishment Study

This study is evaluating three sets of main treatment variables (Table 1): topsoil salvage procedures (fresh vs. stored), mulch method (stubble, surface, stubble + surface, and non-mulched), and level of herbaceous species competition (concurrently seeded grasses vs. no seeded grasses). Sagebrush was seeded similarly within all combinations of the above main treatments using broadcast methods. Figure 1 portrays the field plot design. Each block is divided into two topsoil treatment plots, each of which is split into four stubble treatments plots; each stubble treatment plot is further divided into three grass seeding-rate treatment plots.

The two topsoil treatments are included to evaluate the hypothesis that sagebrush establishment will be enhanced by use of fresh-stripped topsoil instead of stored topsoil (i.e., topsoil that had been stockpiled at least 5 years prior to respreading on mine spoils). It is postulated that freshly stripped topsoil will have a minimum loss of fertility, VAM and, possibly, viability of seed bank sagebrush seeds, and therefore, a higher potential for natural establishment of sagebrush than stored soil.

The mulch treatments are to test the hypothesis that modifications of seedbed conditions will improve establishment of surficially seeded sagebrush. Mulches are known to modify the seedbed microclimate with regard to temperature and moisture. Two mulches are being tested, alone and in combination: a grain stubble and a surface application of hay/straw mulch. Grain stubble has been found effective in trapping snow, modifying diurnal temperature fluctuation, and increasing water infiltration and storage in the soil. Because of these benefits, researchers found stubble mulching to result in greater grass seedling establishment than that with other mulching practices; the same results would be expected for sagebrush, particularly when surface seeded. The surficially applied hay/straw mulch will likely have little effect on snow accumulation, but may beneficially modify seedbed microclimate through water conservation and temperature moderation; it also may protect sagebrush seeds and seedlings from physical and desiccative effects of wind and/or insolation.

The grass seeding treatments are to evaluate the hypothesis that sagebrush will be more effectively established in absence of competition from concurrently seeded herbaceous species. The three treatments are absence and two seeding rates of a mixture of vigorous cool-season, native perennial grasses.

Pioneer Plant Study

This study involves two sets of main treatment variables (Table 1): topsoiling procedures (fresh vs. stored, for the same purposes described in the Establishment Study), and shrub seeding procedures. Mulch method (grain stubble) and level of seeded herbaceous species competition (no seeded grasses) is held constant under all main treatment combinations. The shrub seeding treatments imposed on each topsoil treatments are: a) seeded to sagebrush, b) seeded to fourwing saltbush, c) one year delayed seeding of

Table 1. Treatments applied in "Establishment" and fourwing saltbush "Pioneer Plant" studies. All combinations of main treatments will be implemented within each study.

Treatments	Establishment Study	Fourwing Saltbush Pioneer Plant Study
TOPSOIL	1. Fresh Topsoil 2. Stored Topsoil	1. Fresh Topsoil 2. Stored Topsoil
MULCH	1. Stubble Mulch 2. Surface Mulch 3. Stubble + Surface Mulch 4. Control (no mulch)	Not varied (Stubble mulching will be practiced on all treatment combinations)
COMPETITION	1. Seeded Cool-Season Grass Mixture 2. Control (no seeded grasses)	Not varied (No grasses will be seeded)
SHRUB SEEDING	Not varied (sagebrush will be seeded on all treatment combinations)	1. Fourwing saltbush seeded Year 1 and overseeded with sagebrush Years 2 and 3. 2. Sagebrush seeded Year 1 and overseeded with sagebrush in Years 2 & 3. 3. Delayed seeding: no shrubs seeded Year 1, sagebrush initially seeded in Year 2 and overseeded in Year 3. 4. Control (no shrubs seeded)

sagebrush, and d) an unseeded control. After the first growing season for seeded shrubs, treatments a), b) and c) will be over-seeded annually with sagebrush to assure that viable seed is present each spring. The experimental design (Figure 1) divides each block into two topsoil treatment plots, each of which are further split into four shrub seeding treatment plots.

The topsoil and shrub seeding treatments allow testing for two contrasting hypotheses. The first, hereafter referred to as the "exclusion" hypothesis, is that fourwing saltbush seeding rates greater than 2.2 kg/ha (26 seeds/m^2) result in monotypic stands that exclude invasion of other species, particularly climax shrubs such as sagebrush. It has been suggested that if seed mixtures contained more sagebrush and less fourwing saltbush, more sagebrush would establish on reseeded mined lands.

The contrasting view, hereafter referred to as the "pioneer plant" hypothesis, is that planting sagebrush and other climax plants before sufficient soil improvement (biological and physical) has occurred predestines poor survival of climax plant seedlings. It is postulated that fourwing saltbush is a pioneer species that can be used to prepare the site for the later-seral species big sagebrush. Saltbush densities of one plant/m^2 may not exclude sagebrush, but instead may promote the soil improvement necessary for sagebrush to establish and survive. If this hypothetical relationship is valid, the most successful and economical method of obtaining healthy stands of sagebrush may be to initially plant a suitable pioneer species such as fourwing saltbush. The rationale for this view is: a) the perceived need for disturbed soils to regain, through effects of the pioneer species, predisturbance levels of VAM and other developmental attributes required to support sagebrush populations, and b) the beneficial modification of seedbed microclimate that may occur with the establishment of a pioneer shrub species. Fourwing saltbush has been previously proposed and justified as an effective pioneer species that will promote the desired soil and microclimate changes.

Comparisons of vegetation responses among the various treatment combinations will allow us to evaluate sagebrush establishment, survival and plant succession with and without fourwing saltbush as a pioneer species. If the exclusion hypothesis is true, there will be little interaction between topsoil and shrub seeding treatments. Plots seeded to sagebrush only will have the greatest, and plots seeded to fourwing saltbush will have the least sagebrush development. Conversely, there will be significant topsoil and shrub seeding treatment interactions if the pioneer plant hypothesis is true. In that case, sagebrush development on stored topsoil should be greater where fourwing saltbush was established than where it was not. Sagebrush should also have greater development on the fresh topsoil than on stored topsoil. In all treatments, survival of sagebrush seedlings should increase as soils and plant communities develop. Proper evaluation of the pioneer plant theory will require additional years beyond the period covered by this proposal.

PROGRESS REPORT

The project was initiated January 1, 1991 and is being carried out in cooperation with North Antelope Coal Company, north of Douglas. Mr. Scott Belden, Environmental Supervisor with North Antelope Coal Company, is our site coordinator and cooperator.

Establishment Study

Topsoil source had a significant affect on sagebrush emergence, first year survival, and second year seedling establishment (Table 2). Seedling emergence and establishment the second year after seeding was unexpected. Young and Evans (1989) found no detectable seed reserve within 6 months after seed dispersal, and concluded that viability was short-lived. Our data indicates that sagebrush seed broadcast in February 1992 also produced seedlings in 1993. In fact, the number of sagebrush seedlings observed in 1993 was generally several fold greater than those counted during the first year after seeding.

The effect of mulch type on sagebrush seedling establishment has become less important (Table 2). During the first year after seeding the stubble and surface mulch were superior to the combination of the two; however, the cumulative effect of two years of seedling establishment exhibits little difference between the mulch types except for the control (no mulch). The data continues to indicate that microsite climate may play a significant role in sagebrush germination and early establishment.

Grass competition continues to play a significant role in establishment and survival of big sagebrush (Table 2). The number of sagebrush seedlings established when no grass competition was imposed is over 4 times that when a typical grass seeding rate was used or when a rate two times the normal rate was used. This data suggests that grass competition significantly affects sagebrush establishment from seed and probably will continue to limit recruitment of shrubs.

Sagebrush seedlings were collected from the various treatment plots and evaluated for VAM infection. The plants collected were considered to be those that emerged in 1992 and were outside of the permanent 1 m^2 quadrats used to monitor seedling emergence and development. VAM infection percentage was very consistent and varied little between topsoil source, mulch type and grass competition (Table 3). The lack of VAM infection percentage differences may reflect: (1) that the VAM inoculum was adequate in both the stockpiled and fresh stripped topsoil, (2) that only those sagebrush seedlings that were infected had survived early seedling stages, and/or (3) that VAM inoculum had built up to levels necessary for infection in the stockpiled topsoil through reintroduction via soil movement and biological development (Loree and Williams, 1984).

The large increase in sagebrush seedlings in 1993 was surprising, especially the large increase observed between the June and October counts. This increase can be attributed to two things: (1) the small sagebrush seedlings were difficult to observe during the June count because of small dense annual weeds and (2) the precipitation during the months of June, July, and August was significantly above normal and the temperatures for that period were below normal which allowed germination and establishment of sagebrush after the June observations were made.Mr. Scott Belden, Environmental Supervisor at North Antelope Coal Company observed delays of over a month in grass emergence on areas reseeded this spring due the below normal temperatures.

Table 2. Sagebrush seedling numbers (seedlings/m^2) as affected by topsoil source, mulch type, grass competition and time.

Treatment Variable	Spring 92	Fall 92	Spring 93	Fall 92
		seedlings/m^2		
Topsoil Source				
Fresh	1.52	1.24	2.52	4.50
Stockpiled	0.03	0.03	0.48	2.26
Mulch Type				
Stubble	1.17	0.96	1.99	4.33
Surface	1.25	1.04	1.89	4.18
Stubble + Surface	0.66	0.54	1.68	3.12
Control	0.01	0	0.43	1.99
Grass Competition (kg PLS/ha)				
0	1.88	1.60	3.05	6.66
16	0.34	0.21	0.74	1.98
32	0.09	0.37	0.71	1.56

Table 3. VAM Infection Percentage of Sagebrush Seedlings

Treatment Variable	% Infection	Number of Seedlings
Topsoil Source		
Fresh	66	66
Stockpiled	76	66
Mulch Type		
Stubble	73	36
Surface	71	36
Stubble + Surface	72	36
Control	67	24
Grass Competition (kg PLS/ha)		
0	73	69
16	68	63

Pioneer Study

Sagebrush seedling numbers on the sagebrush plots were much greater than the fall 1992 counts (Table 4). Counts of fourwing saltbush indicates little mortality during the second growing season. Sagebrush establishment on the fourwing saltbush plots was roughly half of what established on the delayed sagebrush plots. By an examination of the pattern of plant occurrence in sample quadrats, we may be able to determine if this pattern is due to the influence of the saltbush seedlings or a random occurrence. The number of sagebrush seedlings on the saltbush plots is comparable to that counted on the fresh topsoil-delayed sagebrush treatment. Stockpiled topsoil plots continue to have more sagebrush seedlings present than observed on the fresh topsoil plots, which is a reverse of what we found on the Establishment Study. The reason for this remains unclear, unless it is related to microsite climate differences resulting from the greater annual forb growth on the fresh topsoil treatments.

Future Plans

Soil biological and chemical qualities are being evaluated on samples collected this summer. Sagebrush seedling density will be measured in late September.

Because all Pioneer Study plots, except the control, have adequate seedling numbers (>2 seedlings/m^2) we have decided not to overseed the saltbush plots this coming winter. This adjustment in the plan will allow us to more accurately follow seedling survival among the various treatments.

We are seeking to continue both the Establishment and Pioneer Study phases of this research to further evaluate the role of VAM in sagebrush survival and growth. We are also presently using photographic methods to evaluate both the fourwing saltbush and sagebrush seedlings to better understand the pioneer plant relationship. Final data collection and interpretation of the Pioneer Study will be accomplished outside of the time frame of the present project.

Table 4. Sagebrush and fourwing saltbush seedling numbers as influenced by seeding treatment.

Treatment	Topsoil Source	Spr92	Fall92	Spr93	Fall93
		seedlings/m^2			
Sagebrush seeded 1st and 2nd year	Stockpiled	1.3	0.4	7.4	10.3
	Fresh	0.2	0.1	3.5	3.8
Sagebrush seeded 2nd year only	Stockpiled	0	0	3.4	6.2
	Fresh	0	0	3.9	6.3
Saltbush seeded 1st and Sagebrush 2nd year	Stockpiled	(3.9)	(3.5)	(3.9)0.9	(3.3)0.9
	Fresh	(4.7)	(4.2)	(4.5)2.0	(4.7)3.7
Control (not seeded)	Stockpiled	0	0	0	0
	Fresh	0	0	0	0

Numbers in ( ) are saltbush seedlings/m^2

Literature Cited

Loree, M. A. J. and S. E. Williams. 1984. Vesicular-arbuscular mycorrhizae and severe land disturbance. pp. 1-14. In: S. E. Williams and M. F. Allan (eds.) VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. Univ. Wyo. Agr. Stn. Rep. SA1261.

Young, J. A. and R. A. Evans. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Science 37:201-206.

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

T.A. WESCHE, H.W. LOWHAM, R.L. DADDOW, M.E. SMITH

SEMI-ANNUAL REPORT #4 FOR THE ABANDONED COAL MINE LAND RESEARCH PROGRAM

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

PRINCIPAL INVESTIGATORS

Thomas A. Wesche - University of Wyoming and Wyoming Water Resources Center

Hugh W. Lowham - U.S. Geological Survey

Richard L. Daddow - U.S. Geological Survey

Mark E. Smith - U.S. Geological Survey

GRADUATE RESEARCH

A CLASSIFICATION OF DRAINAGE BASINS IN THE EASTERN POWDER RIVER COAL FIELD OF WYOMING

Anthony J. Anderson - University of Wyoming

CHARACTERIZATION OF DRAINAGE NETWORKS FOR MINE LAND RECLAMATION IN THE EASTERN POWDER RIVER BASIN, WYOMING

Lee E. Jensen - University of Wyoming

PROGRESS REPORT PERIOD: 5/26/93 - 10/8/1993

Introduction

The University of Wyoming and U.S. Geological Survey project team members have implemented the research plans to accomplish the overall project objectives. These objectives are to: 1) inventory, review, and summarize design procedures being used for reconstruction and reclamation of drainage basins and stream channels in the Powder River coal field of Wyoming, emphasizing the extent that the geomorphic approach is used for reconstruction design; 2) develop a classification system for drainage basins and stream channels in the Powder River coal field of Wyoming based on the natural, physical characteristics of selected groups of small drainage basins; and 3) analyze and summarize the geomorphic characteristics of different classes or types of drainage basins and stream channels, thereby developing geomorphic methodology and criteria for the design of reconstructed drainage basins and stream channels.

Progress During the Report Period

Drainage Basin Analysis

Drainage basin delineation on USGS 1:24000 topographic maps was completed. Sixty-four (64) third order basins, 128 second order basins, and 192 first order basins were digitized and basin measurements were taken using AUTO-CAD release 12 c2. Elevation values were determined to the nearest 5 feet from contour analysis of the topographic maps. Vegetation and soils maps were generated at 1:24000 scale using digital data from the University of Wyoming Department of Botany GAP analysis and the SCS's STATSGO databases. These maps were used to estimate the dominant vegetation and soils types within each basin. A precipitation contour map was generated with the ARC-INFO geographic information system using data from the 1961-1990 National Weather Service thirty year normals. Due to the sparsity of the data points in the study area, the generated map will may be revised to reflect other available data sources.

A database was compiled with 28 variables for each third order basin. Lotus 1-2-3 was used to calculate secondary variables and to compile the database. The database was entered into the SAS statistical software package and initial multivariate and univariate statistical analyses were performed. Interpretation of the multivariate statistical analyses is still underway but initial analyses have indicated substantial variability in drainage basin morphology across the study area. Summary statistics for key variables are listed in Table 1.

Drainage Network Analysis

The on-site field investigaton for the characterization of drainage networks was completed on schedule by September 1, 1993. Sixty stream channels were investigated at various geographic locations within the study area. There were 13 third order networks, 19 second order networks, and 28 first order networks investigated at

the field level. The data collected during this investigation included: 1) surveyed cross sections at several locations along each study reach; 2) surveyed longitudinal profiles of first and second order networks; 3) bed and bank soils samples taken at 10 locations on each study reach; 4) estimates of Manning's "n" made for study reaches with stream channels; 5) notations concerning the type and composition of vegetation communities; 6) detailed notations describing characteristics of each cross section and the study reach in general; and 7) notations were made concerning distinguishing geologic and geomorphic features.

Preliminary Results

The most notable preliminary results at this time are qualitative observations from the on-site investigation of the drainage networks. These findings are: 1) there are two different types or classes of drainage networks; and 2) stable drainage networks are predominately lacking in the study area. The two drainage network types observed were labeled "channel" and "valley". Virtually all third order study reaches contained moderate to well defined stream channels. The first and second order study reaches were predominately classified as "valley". These first and second order reaches did not contain stream channels. Additionally, those reaches classified as valley were of three main types: flat-bottom valley, U-shaped valley, and V-shaped valley. Examples of the different drainage networks will be shown at the meeting October 8, 1993.

Future Work

Statistical analysis of the drainage basin data will continue through the fall of 1993 and into the spring of 1994. Drainage basins will be clustered using statistical procedures and we will attempt to identify defining characteristics of each category. Regression equations and graphs such as those in our presentation will be generated for the individual strata or categories of drainage basins. It is hoped that the categorical regression equations and graphs will yield significantly improved levels of confidence.

Analysis of the stream channel data will continue and relationships similar to those presented at the meeting will be attempted. It is anticipated that stream channel characteristics will be correlated to strata derived from the drainage basin analysis. Completion of the two Masters of Science theses is scheduled for late spring or early summer of 1994.

Table 1. Preliminary Summary Statistics for Key Variables for First, Second, and Third Order Basins.

ORDER=1 N=192 Variable		Mean	Range	Stan.Dev.
Area	($Miles^2$)	0.22	0.88	0.151
Basin Relief	(Feet)	158	305	65.123
Main Chan. Length	(Miles)	0.65	1.51	0.289
Relief Ratio	(Feet/Mile)	224	662	105.267
Drainage Density	($Mile/Mile^2$)	3.49	7.31	1.402
ORDER=2 N=128 Variable				
Area	($Miles^2$)	1.01	6.68	0.934
Basin Relief	(Feet)	216	330	69.774
Main Chan. Length	(Miles)	1.687	6.88	1.059
Relief Ratio	(Feet/Mile)	166	451	78.446
Drainage Density	($Mile/Mile^2$)	3.41	5.78	1.100
ORDER=3 N=64 Variable				
Area	($Miles^2$)	3.42	8.17	2.101
Basin Relief	(Feet)	296	430	90.130
Main Chan. Length	(Miles)	3.94	8.99	1.949
Relief Ratio	(Feet/Mile)	115	269	50.019
Drainage Density	($Mile/Mile^2$)	3.30	3.70	0.744

SPECIFICATION AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

K.D. BASHAM, B.A. SUPRENANT, W.L. JOHNSON

SPECIFICATIONS AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

Principal Investigators:

Kim D. Basham, Ph.D., P.E.
CTC-GEOTEK, INC.
155 South Navajo
Denver, CO 80223
303/698-1050
FAX 303/698-1053

Bruce A. Suprenant, Ph.D., P.E.
Department of Civil, Environmental & Architectural Engineering
University of Colorado
Campus Box 428
Boulder, CO 80309-0428
303/492-7636

Consultant:

Wayne L. Johnson, PE & LS
Johnson-Fermelia Co. Inc.
1515 Ninth Street
Rock Springs, WY 82901
307/362-7519

Amount: $59,000

Project Duration: April 10, 1993 to March 31, 1994

Abstract:

Abandoned mines underlay many areas of Wyoming. As mine cavities collapse they can cause settlement (subsidence) and ground distortions on the surface which may damage or even destroy buildings and affixed utilities. To increase the ability of building officials, contractors, architects, engineers, and homeowners of Wyoming to mitigate subsidence related building damage, the authors are reviewing and updating the *Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence* and developing a document entitled *Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence*. The purpose of the first document, developed by the University of Wyoming in 1988 and funded by the WY DEQ/LQD, is to provide construction specifications and recommendations for new structures built in areas with a potential for mine subsidence. The intend of the construction specifications and recommendations document is to provide guidelines for residential construction that minimize subsidence related building damage. The document also serves as an essential part of the qualifying process to insure new structures through the Wyoming Mine Subsidence Insurance Program. The second document or repair manual will consist of guidelines, recommendations, and repair schemes for repair of residential structures damaged by mine subsidence type ground movements. The repair manual will help architects, engineers, construction professionals, and homeowners of Wyoming to efficiently devise and execute suitable repair schemes. The repair manual will also set a standard for optimizing subsidence related building repair which will help minimize future repeat subsidence damage and insurance reclaims. To help introduce both documents, the investigators plan to develop information pamphlets on mine subsidence, related building damage and repair schemes. Information pamphlets will provide initial guidance with regards to subsidence to homeowners and the building community. In summary, the results of this project will enhance the ability of Wyoming communities to minimize the potential residential building damage caused by mine subsidence and to optimize subsidence repair schemes.

Project Goals:

1) To review and update the DEQ - Land Quality Division's document entitled *Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence*.

2) To develop and publish a document entitled *Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence*.

3) To develop information pamphlets to introduce both documents as well as an overview of subsidence related problems in Wyoming to homeowners and the building community.

Progress:

Phase I Develop and publish 2nd edition of

Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence

25 Percent Complete

Phase II Develop and publish

Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence

60 Percent Complete

Funding 52 Percent Remaining

INVENTORY OF KEMMERER COAL COLLECTION

P. MALMBERG

GUIDE TO
KEMMERER COAL COMPANY RECORDS LOCATED IN KEMMERER, WYOMING
1897-1950

32 Cubic Feet

ACCESSION NUMBER 93DN1

Prepared by Peter Malmberg
August 1993

INTRODUCTION

Kemmerer Coal Company
Records, 1897-1950
32 Cubic Feet (32 archival storage boxes)
Accession Number 93DN1

The Kemmerer Coal Company Records were donated by the Pittsburg-Midway Coal Company to the Fossil Country Frontier Museum of Kemmerer, Wyoming 1992. The records were received in good condition and have been kept in the order (primarily chronological) in which they were found. The photographic series was, however, received in no particular order and has been arranged by subject and size.

The collection should be cited as: Kemmerer Coal Company Records, Accession Number 93DN1, Box Number, Folder Title, Fossil Country Frontier Museum, Kemmerer, Wyoming.

HISTORY

The Kemmerer Coal Company was founded in 1897 by M.S. Kemmerer and P.J. Quealy. At the same time they established the Unita Improvement Company, the Frontier Supply Company, and the town of Kemmerer, Wyoming

In 1897 the Oregon Short Line Railroad agreed to build tracks to the Kemmerer-Quealy Coal properties. The track was completed on October 5, 1897. During the first month 4,000 tons of coal were shipped out. From April 30, 1900 to April 30, 1901, total production was 513,329 tons. This was the largest yearly production for a single organization in either Utah or Wyoming.

P.J. Quealy, M.S. Kemmerer, and their descendants were involved with various companies and corporations over the next several decades. Some of these organizations included the First National Bank of Kemmerer, the Wyoming Timer Company, the Wyoming Stockmen's Loan Company, the State Bank of Cokeville, Quealy Sheep and Livestock Company, State Bank of Pinedale, State Bank of Big Piney, Bankers Trust Company of Salt Lake City, First National Bank of Rock Springs, the National Coal Association, the National Copper Bank, Continental Livestock Loan Company, Lincoln Service Corporation, various ranches and oil fields, and the Gunn-Quealy Coal Company. The Gunn-Quealy Coal Company later became a subsidiary of the Kemmerer Coal Company.

In 1981 the Kemmerer Coal Company was purchased by the Gulf Oil Company. The Pittsburg-Midway Coal Company acquired the company from Gulf Oil in 1983.

SERIES DESCRIPTION

The Kemmerer Coal Company records are arranged in three series:

Series I. Correspondence, 1897-1950. 25 Cubic Feet (Twenty-five archival boxes). Arranged in original order. Contains correspondence about various companies, lands, accident reports, as well as business and labor correspondence.

Series II. Photographs, 1894-1950. 3 Cubic Feet (Three standard archival boxes). Arranged by subject and size. Contains photos of a variety of area coal communities, mines, and citizens.

Series III. Ledgers, 1896-1950. 5 Cubic Feet (Three large boxes). Arranged by subject and size. Contains information about the business operations of various companies.

SCOPE

The Kemmerer Coal Company Records provide insight into the development of one of the most important early coal mining operations in the American West. This collection should be a valuable resource for a variety of researchers and scholars.

KEMMERER COAL COMPANY COLLECTION: TECHNICAL REPORT

A variety of processes were used in order to make the Kemmerer Coal Company available to researchers. These steps included placement of photographs in Mylar plastic sleeves, storage of correspondence in acid free folders, coating newspaper articles with deacidification solution or wrapping them in tissue paper, and cleaning documents with absorene wallpaper cleaner or archival groomsticks. In addition, the entire collection is now stored in standard acid-free archival storage boxes.

Initial processing used a series of steps. Papers, photographs, and ledgers were first examined to determine their condition. Papers which seemed dirty were dusted first with a light archival brush. Following this procedure, wallpaper cleaner of archival groomsticks (a kind of silly putty material) were used to remove dirt ingrained in the paper fibers. Newspaper articles (which are very acidic and deteriorate rapidly) were either sprayed with deacidification solution or wrapped in tissue paper. Photos were encased in Mylar plastic sleeves after being removed from frames or after picture mountings were cleaned with wallpaper cleaner. All metal fasteners which could damage the records (except grommets) were removed from papers and photographs. After these steps were taken, all papers, photos and newspaper articles were placed in acid free folders and stored in acid free boxes. Ledgers were also inspected and, after their condition was documented, placed in acid free boxes. The collection is stored in a climate controlled vault in the Lincoln County Wyoming Library.

The care and storage afforded to the collection should ensure that this valuable historical resource will survive indefinitely.

GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

S.B. SMITHSON, M.C. HUMPHREYS, N.K. BOYD

Detection of the Subsurface using High Resolution Seismic Reflection and Ground-Penetrating Radar

By M. C. Humphreys, N. K. Boyd and S. B. Smithson

We began conducting our 1993 AML funded field research in August of 1993. Utilizing high resolution seismic reflection techniques and ground-penetrating radar, our aim is to detect and image voids and potential subsidence zones in areas previously mined for coal. We were able to commit funds to purchase a high resolution seismic system after the beginning of the new fiscal year in July of 1993. By waiting a few months we bought a more advanced system than was available earlier. We received our new instrument at the end of July and began equipment testing and modifications before conducting our research. One of the first needs was for a suitable recording truck. We chose to modify an existing instrument cab to fill our current needs. We mounted the instrument cab on one of our existing trucks and performed all the necessary re-wiring. Batteries charged by solar panels provide the power for the seismic system and associated computers, cable testing and switching equipment. The outfitting was done in a little over a week of rather hectic work. We saved a considerable amount of money by modifying some of our existing seismic cables. The cable modifications were done simultaneously while constructing the recording vehicle. We were ready for field testing by August 8th.

The crew made its first trip to the Rock Springs area on the 11th of August. We made a number of preliminary recording tests and conducted our first two major seismic experiments during an 8 day field period. We could not conduct our seismic work concurrently with the ongoing drilling and grouting operations in the area. We found it necessary to work after quitting time for the operations there (6 PM) or to work on Sundays when their work was halted. We, therefore, made several weekend trips to Rock Springs to work when the drilling was stopped. We completed a number of equipment tests, wave propagation studies, and a total of six major seismic experiments.

We received good cooperation with the consulting engineering firm managing the drilling and grouting operations. We had access to their drill holes after their logging and prior to grouting. Thus, we obtained surface to coal-depth velocity information by direct measurement. After initial testing to determine the feasibility of down-hole velocity measurements, we decided that we needed to construct a special down-hole velocity measuring sensor. We built an appropriate sensor and then were able to make a significant number of accurate velocity measurements in areas where we had conducted our seismic experiments. This data is used for determination of travel-time moveout corrections which are applied to the data to enable accurate measurement of seismic reflector depths. A collection of these known velocities over an area will allow for much greater accuracy in imaging the subsurface by the seismic survey.

An important obstacle to overcome is to determine the appropriate time "window" to see reflected energy from a shallow sub-surface layer while minimizing the unavoidable noise which is generated by our energy source. This seismic noise occurs in two forms. The first form is sound waves which travel through the air with predictable and constant velocity. The second form is sound waves which travel along the ground surface from the source to the detectors, masking reflected energy. We have learned a number of techniques to minimize this noise, employing both hardware and software in the subsequent data processing of the seismic data. The conventional method of avoiding this noise problem is to bury the energy source sufficiently deep that surface disturbance does not occur. Unfortunately source burial is prohibitively expensive in high resolution seismic work and nothing is determined about the area between the surface and the source. Our goal is to make seismic measurements of reflective zones at a depth of roughly 100 feet using measurements every two feet or so on the surface with a simple and low cost but repeatable energy source. We have developed two energy sources which generate a sufficient amount of high frequency energy. High frequency sources are important because less surface noise is generated.

We hope to streamline the processing sequence to enable "real time" processing in the field. This "real time" processing provides quality control on data acquisition and the identification of interesting areas for further investigation. We hope that after an initial trial period we will have sufficient knowledge of the problems of high-resolution seismic data processing to permit us to acquired "real time" processed seismic data.

Another part of our project deals with the use of ground penetrating radar and its application to near surface work. We allocated about 1/3 of the grant for the rental of radar equipment to conduct instrument tests. There are only two manufacturers of this equipment in the world and only one of these has a system which is useful for research work. They have only two rental instruments and the scheduling of them was difficult. We had tentatively planned to allocate the months of September and October to doing field work with the radar and we received the radar unit on the 12th of September. We performed a few small equipment tests in the Laramie area and then spent the last week of September in the Rock Springs area doing preliminary radar tests. As the radar unit transmits a broad spectrum energy pulse centered at 100 Mhz, the manufacturer has been forced to reduce the transmitter output significantly to reduce radio frequency interference. Therefore we cannot attain the depth penetration we would like, but ground-penetrating radar will be useful in certain types of near surface research. We have conducted two tests which show spectacular results with ground-penetrating radar and we are currently conducting several experiments which should contribute to the research. We should point out that ground-penetrating radar is an evolving technology and the general predictability of its usefulness is not great. In one case we were very successful at imaging four layers of coal separated by shale and limestone

layers. There was a recognized fault zone exposed at the surface which was easily seen on the radar image. When the radar transmitter and receiver antennas are placed on flat surfaces, such as a road bed, the performance is much better than upon irregular, fragmented, non-homogeneous surfaces. The presence of asphalt or concrete seems to significantly deteriorate the ground-penetrating radar's performance, however areas like graded alleys and dirt roads give vastly superior data.

We are continuing the radar experiments at least through the month of October and we are also planning to conduct both ground-penetrating radar and high resolution seismic experiments in different parts of the state throughout the winter.

TOXICOLOGIC EVALUATION OF CHRONIC SELENOSIS IN WYOMING HERBIVORES

M.F. RAISBECK, E.L. BELDEN, D. O'TOOLE,
J.W. WAGGONER, E.T. THORNE

Toxicologic Evaluation of Chronic Selenosis in Wyoming Herbivores

M. F. Raisbeck, E. L. Belden, D. T. O'Toole, J. W. Waggoner and E. T. Thorne

The principle tasks outlined for the second year of the project are experimentally establishing dose-responses for selenomethionine and selenite in calves. An rather extensive experiment was undertaken this summer to: 1) examine the hypothesis that 5 ppm dietary Se is toxic in native herbivores; 2) compare and contrast the toxicity of inorganic Se salts with that of selenomethionine; and 3) experimentally test our field observation that Se may be immunotoxic.

Animal studies

Yearling beef calves were obtained from the Medicine Bow area and randomly divided into 1 control and 6 treatment groups. Each treatment group was fed either sodium selenite or selenomethionine at one of three dosages (0.15, 0.28, or 0.8 mg/kg Se). The control (basal) diet consisted of relatively low Se (200-300 ppb) native grass hay from the Riverton area, ground to 1" with sufficient additional cottonseed meal and phosphate enriched salt to make up NRC recommended requirements. Se supplements were made up in ground corn cob daily and carefully mixed with the day's ground hay basal diet. All groups were maintained on the basal ration for a 30 day acclimation period prior to initiation of the experiment.

Previous feeding experiments were complicated by the induction of conditioned aversion in cattle by dietary sodium selenite. We hoped to avoid this problem in this summer's experiment by: 1) distributing each day's dose throughout the total day's ration; and 2) feeding each high dose animal immediately adjacent to a control or low-dose animal. This arrangement worked well for the most part; however, one 0.8 mg/kg selenomethionine steer refused to eat after 2 wks on treated rations. He was replaced in the experiment with a similar animal from a research herd west of Cheyenne; however, as a secondary experiment he continued to receive selenomethionine via gelatin capsule for the duration of the experiment.

Samples collected and parameters measured

At three week intervals, steers were given a physical examination, weighed, and blood collected for hematology, immunology, toxicology and clinical biochemistry. Parameters measured included: complete blood counts with differential counts; hemoglobin, total bilirubin, creatinine, urea nitrogen, protein, albumin, and glucose concentrations; blood and plasma selenium concentrations; and glutathione peroxidase, aspartase aminotransferase, alkaline phosphatase, creatine phosphokinase and hydroxybutyrate dehydrogenase activities. At termination of the experiment, each calf was humanely euthanized, necropsied, and

samples taken for conventional histopathology[1], Danscher histopathology[2], and toxicology[3]. These analyses are underway and should be finished sometime this winter. Complete results of this phase of the experiment will be presented at the meeting in May.

First impressions

Although it is premature to draw any broad conclusions from this experiment until all materials are analyzed and the data scrutinized, several observations are worth mentioning.

1) Only the calf which was pilled with selenomethionine showed any outward evidence of toxicity, in this case manifested by the suite of clinical signs commonly referred to as "alkali disease".

2) This animal never showed any evidenceof neurological damage (including impaired vision).

3) Weight loss seemed most directly attributable to inappetance and inability to navigate.

4) In spite of continued dosing, the hoof lesions appeared to be resolving themselves at postmortem.

5) Dosages utilized in this experiment were roughly equivalent to 5, 10 and 25 ppm *total* dietary Se. While no single small scale experiment can be considered to be conclusive, our results to date indicate that the 5 ppm basis of current regulations is conservative for protection of cattle, and by implication other Wyoming grazing species.

---

[1] liver, kidney, adrenals, right ventricular myocardium, left ventricular myocardium, atrial myocardium, interventricular myocardium, thyroids, pancreas, thymus, pituitary, all major divisions of the brain, biceps brachii, extensor carpi radialis, vastus lateralis, biceps femoris, tibialis cranialis, longissimus lumborum, psoas major, ulnar nerve, median nerve, fibular nerve, sciatic nerve, complete spinal cord, trigeminal ganglion, salivary gland, tonsils, tongue, esophagus, rumen, reticulum, omasum, abomasum, duodenum, jejunum, ileum, colon, gall bladder, lung (3 lobes), aorta, kidney, urinary bladder, thyroid, spleen, mesenteric lymph node, hepatic lymph node, bone marrow, digit, and skin.

[2] Liver, heart (LV, RV, IVS), kidney, right frontal cerebral cortex, spinal cord, eyes, optic nerve.

[3] Liver, kidney, urine, hair, skin, hoof, red cells, plasma, brain, biceps brachii, myocardium.

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

G.F. VANCE, K.J. REDDY, L.K. SPACKMAN, S. SHARMASARKAR

Abandoned Coal Mine Land Research Program

Semi-Annual Report

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

George F. Vance and Shankar Sharmasarkar

Department of Plant, Soil and Insect Sciences
University of Wyoming

Katta J. Reddy

Wyoming Water Resources Center
University of Wyoming

Lowell K. Spackman

Wyoming Department of Environmental Quality
Land Quality Division

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

Introduction

Selenium (Se), an element of interest and concern, has the potential of becoming increasingly mobile with time in oxidizing environments. During surface mining activities, materials previously in reducing environments become exposed to atmospheric conditions. This exposure may result in elevated levels of mobile and plant-available Se which subsequently can magnify the potential occurrence of Se biotoxicity. In addition, solubility and mobility of Se in areas disturbed by mining may result in higher levels of Se in surface waters, ground waters, and in resaturated backfill environments. The post-mining land use of a majority of the abandoned and reclaimed coal mine lands is grazing land, pastureland and/or wildlife habitats. If Se mobilization is not attenuated, affected abandoned and reclaimed areas may not be suitable for post-mining land use or may require special resource management considerations. Therefore, appropriate research on soil and backfill material is necessary to characterize Se solubility, mobility and speciation to determine its fate in the reclaimed landscape.

Objectives

The main objective of this research project is to examine the geochemistry of Se in abandoned and reclaimed coal mine sites, and native rangelands. The project has been divided into four research tasks:

- development of a rapid and cost effective method for determining Se species in backfill and soil materials of abandoned and active coal mine sites,
- examination of solid-phase and solution speciation of Se in the rooting-zone of mine soils for correlation to plant uptake,
- characterization of Se adsorption/desorption and precipitation/dissolution processes controlling Se mobility in backfill and soil environments,
- determination of plant uptake of Se at coal mine lands and other affected sites that can be correlated to Se solid-phase and solution-phase speciation.

Selenium occurs naturally in several chemical forms. We propose that the analysis of the factors that control Se speciation and the direct analysis of Se species can be used to characterize and predict the processes that control Se solubility, mobility, availability, and plant uptake. This information will assist in designing preventative and/or remediation schemes for abandoned, reclaimed and active coal mine lands.

Survey of Abandoned Coal Mine Lands in Wyoming

Several sources of information, which were described in the third semi-annual ACML report, were used for locating research sites on abandoned and active coal mine lands. A comprehensive description of our survey of potential abandoned coal mine sites is available in an interim report submitted to the Office of Research, University of Wyoming on October 18, 1991.

Site Selection

Five surface coal mines located in north, central and southern Powder River Basin were selected and sampled during summer, 1991. During the summer 1992, the same five mines and two additional mines were sampled; a reclaimed abandoned coal mine located near Rock Springs and a reclaimed uranium mine located in the southern part of the Powder River Basin.

Field Work

In both 1991 and 1992, plant, soil, and backfill or overburden samples were collected from abandoned, reclaimed and native sites located in the Powder River Basin and near Rock Springs. Forty three sites were established within thirteen transects located on the seven different mines. In both 1991 and 1992, the five dominant plant species at each site were sampled.

Sample Preparation

All the soil, backfill or overburden, and plant samples have been logged in and prepared for chemical analysis. The plant samples were oven-dried at 50-60°C for 24 hours and then ground to 60 mesh using a Wiley Mill. The soil, and backfill or overburden, samples were divided in two, using a Riffle Splitter. One part was crushed with a hammer covered with cheese cloth and sieved to 10 mesh and the other air dried and stored in polybags.

Laboratory Studies and Results

Suitable Instrumentation for Se Analyses: Both Ion Chromatography (IC) and Atomic Absorption Spectrophotometry with Hydride Generation (AAS-HG) techniques were used to analyze and speciate Se. For IC, the detection limit is in the range of 10 to 20 µg/L and the limit of quantification is approximately 500 µg/L. For AAS-HG, the detection limit is approximately 1 µg/L and the limit of quantification is approximately 200 µg/L. Interferences from SO_4^{2-} concentrations above 1000 mg/L can limit the effectiveness of IC for Se speciation. Studies have been performed using both techniques and results from both correspond well, except for the soils having very high level of sulfate. For the high sulfate soils AAS-HG is a better method of Se speciation than IC. However, it is important to note that IC has the capacity to directly speciate Se, whereas AAS-HG measures total Se and selenite, but in separate runs.

Selenium Extraction Methods: The extraction of Se by the four different techniques for all the soil and backfill samples collected in 1991 and 1992 has been completed. Results from the extractable Se analysis indicate the following trend in the amount of Se extracted: Phosphate > AB-DTPA > Hot Water > Saturated Paste. In a number of sites, AB-DTPA extractable Se was found to be greater than the WDEQ-LQD Guideline No. I (1984) suitability limit of 0.1 mg/kg. Results of this work will be used to correlate soil-plant Se levels.

Solution Se Speciation: Solution Se species have been quantified in water, hot water ($CaCl_2$), AB-DTPA, and phosphate extracts of soil, backfill, and overburden material. Both IC and AAS-HG techniques were found to be useful in speciating solution Se. The IC method quantifies both SeO_3^{2-}, and SeO_4^{2-} in solution without the need for sample pretreatment or HCl reduction (needed for AAS-HG). For aqueous extracts of low sulfate soils, both AAS-HG and IC work well. AAS-HG is the accepted method for high sulfate soils, backfill, and overburden materials. Some abandoned mine sites have been found to have very high Se and low sulfate, in such cases IC is more useful. Based on results from both methods, SeO_4^{2-} has been found to be the predominant solution Se specie.

Solid Se Speciation: Soil samples were fractionated sequentially for solid phase Se by 0.25M KCl (fraction 1), 1M KH_2PO_4 (fraction 2), 4*N* HCl (fraction 3), $KClO_4$, + 12 *N* HCl (fraction 4), and concentrated HNO_3 + $HClO_4$ + HF (fraction 5). Also mixed acids (concentrated HNO_3 + $HClO_4$ + HF) digestion for total Se was done. Each solution was analyzed for Se^{+4} and Se^{+6} species using AAS-HG. Selenium fractions from sequential extractions of these materials provides information on soil-plant relationships and mobility potential: Fraction 1 corresponds to the water soluble Se that can leach down the profile with the percolating water; Fraction 2 represents the ligand exchangeable Se that is adsorbed onto the mineral surface; Fraction 3-Se can go into soil solution during any acid leaching process; Fraction 4 suggests the presence of organic bound Se that can be mineralized; Fraction 5 corresponds to the siliceous Se that can be released through weathering. The dominant Se specie present in the different fractions corresponds to previous results for solution Se speciation, i.e., SeO_4^{2-} is more prevalent than SeO_3^{2-}.

Adsorption and Desorption Studies: Adsorption-desorption studies have been conducted using a batch technique. These studies are important for: a) determining Se adsorption capacity of the soils, backfill, and overburden materials, b) identifying how solubility, mobility, and availability of Se is governed by adsorption, and c) correlating Se adsorption. Selenite has been found to be the potential adsorbate and the degree of sorption increases with decreasing pH. There is a large difference between adsorption and desorption, which indicates Se immobilization through precipitation processes. Adsorption and desorption studies suggest the soil, backfill, and overburden sorption is great, and desorption is generally 50 percent of that which is adsorbed.

Precipitation and Dissolution Studies: Precipitation studies are being conducted from both undersaturation and supersaturation conditions. Soil, backfill, and overburden, as well as pure minerals, are being used in these studies; results will determine the potential solid phases controlling the solution Se chemistry. The results of the precipitation studies will be analyzed using the speciation model MINTEQA2 or GEOCHEM. Data from the solubility studies with the solid phases will also be compared to the existing thermodynamic predictions found in the literature. These studies are useful for: a) characterizing solubilities and mobilities of different Se species and b) determining Se levels with respect to solid phase speciation. Studies thus far indicate SeO_3^{2-} is effectively removed from solution by metal cations, leaving SeO_4^{2-} in solution.

Plant Se Characterization: Total plant Se has been analyzed in all the 1991 (189 samples of 59 different species) and 1992 (202 samples of 66 different species) samples. A large number of samples contained Se levels >5 mg/kg. Plant data will be statistically correlated to soil-data to determine possible relationships.

Soil Chemical and Pedological Characterization: Laboratory studies have been done to determine pH, Eh, EC, soluble sulfate, soluble carbon (TC, IC, DOC, NPOC), and Se (total and extractable). These results will be statistically evaluated for correlations with plant Se data.

Project Outcome

We anticipate the results of this research may provide information to predict the availability of Se to plants and the migration of Se to sensitive aqueous environments. This information can be used to aid in the development of suitability limits for regraded zone materials. The information may also be useful in designing remediation schemes by identifying materials that can fix mobile Se species. The identification of solid and solution phase Se species that correlate with plant Se can result in the development of methodologies to fix Se in plant unavailable forms. The results of this

study should also provide information on where elevated Se spoil materials can be placed in the backfill environment (i.e. reduced, oxidized, or degree of saturation).

Personnel Involved with Project

Doug Bonett, Associate Professor of Statistics, is supervising all project statistics. Additional personnel contributing to this project include a Post-Doctoral Scientist, Dr. Micheal J. Blaylock, Research Associate, Tim Brewer, and several undergraduate laboratory assistants.

Presentations:

Blaylock, M.J. and G.F. Vance. 1993. Relationships Between Chemical Properties of Selenium in Soil Materials to Potential Plant Uptake and Mobility. Workshop: Fundamentals of Selenium Biogeochemistry and Importance to Ecosystem Integrity. Sixth Billings Reclamation Symposium. Billings, Montana.

Blaylock, M.J. and G.F. Vance. 1993. Plant Uptake and Metabolism of Selenium. Workshop: Fundamentals of Selenium Biogeochemistry and Importance to Ecosystem Integrity. Sixth Billings Reclamation Symposium, Billings, Montana.

Vance, G.F and M.J. Blaylock. 1993. Analytical Advances for Selenium Determination in Soil and Overburden. Selenium Forum. Sixth Billings Reclamation Symposium. Billings, Montana.

Sharmasarkar, S. and G.F. Vance. 1993. Mechanistic Role of Adsorption and Precipitation Processes in Controlling Selenium Mobilization in Mine Soils. Pacific Division of the American Association for the Advancement of Science Annual Meeting. Missoula, MT.

Tanaka, E.F., S. Sharmasarkar, and G.F. Vance. 1993. Sequential Extraction of Selenium in Mine Soils. Minority High School Students Research Program, University of Wyoming. Laramie, WY.

Abstracts for Future Presentations:

Sharmasarkar, S. and G.F. Vance. 1993. Importance of Solid Selenium Speciation for Understanding Soil Water Contamination in a Reclaimed Abandoned Mine Environment of Wyoming. 1993. American Water Resources Association, Wyoming State Section, Sixth Annual Meeting, Laramie, WY.

Sharmasarkar, S. and G.F. Vance. 1993. Environmental Implications of Soil and Plant Selenium Chemistry in Range and Reclaimed Coal Mine Lands within the Powder River Basin, Wyoming. Soil Science of America Annual Meeting. Cincinnati, OH.

Sharmasarkar, S., G.F. Vance, K.J. Reddy, and M.J. Blaylock. 1993. Geochemical Immobilization of Selenium in Surface Coal Mine Land Environments. Soil Science Society of America Annual Meeting. Cincinnati, OH.

Sharmasarkar, S. and G.F. Vance. 1994. Application of Partial Fractionation and Speciation Techniques for Predicting Groundwater Contamination by Soil Selenium Movement. 1994. American Water Resources Association, Annual Summer Symposium, Jackson Hole, WY.

Publication:

Spackman, L.K., L.E. Vicklund, G.F. Vance, P.K. Carroll, D.G. Steward, and J.G. Luther. 1993. Standard operating procedures for the sampling and analysis of selenium in soil and overburden/spoil material. University of Wyoming College of Agriculture Miscellaneous Bulletin. (in progress)

THE ROLE OF NATURAL ORGANIC SOLUTES IN THE MOBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

R.B. SEE, K.J. REDDY, G.F. VANCE, A.A. FADLEMAWLA

SEMI-ANNUAL REPORT #5
THE ROLE OF NATURAL ORGANIC SOLUTES IN THE SOLUBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

Randolph B. See, U.S. Geological Survey
Katta J. Reddy, Wyoming Water Resource Center
George F. Vance, University of Wyoming
Amr A. Fadlemawla, University of Wyoming

SUBMITTED TO
THE ABANDONED COAL MINE LAND RESEARCH PROGRAM
October 1, 1993
Office of Research
University of Wyoming
P.O. Box 3355
Room 201, Old Main
Laramie, WY 82071-3355

INTRODUCTION

Natural organic solutes may play an important role in the solubility of selenium in coal mine backfill aquifers. A better understanding of the processes involving organic solute-selenium interactions could provide information for improving coal mining reclamation techniques. The specific objectives of this research are:

1. To characterize the chemical and physical properties of surface coal mine backfill and associated ground waters,
2. To determine the role of natural organic solutes on selenium sorption/desorption and precipitation/dissolution processes, and
3. To quantify the effects of organic solutes on the solubility of selenium in reclaimed coal mine backfill aquifers.

The information obtained from this research will increase our understanding of processes that influence the solubility of selenium in coal mine backfill ground-water systems.

SITE SELECTION

Three field sites with existing wells were selected in reclaimed areas at two large surface coal mines in the Powder River Basin. The mines are referred to by letter designation (A and B) throughout this project because of agreements with the companies not to identify the mines by name. Two sites were investigated at mine A (A-1 and A-2) and one site was investigated at mine B (B-1).

SAMPLE COLLECTION

Six backfill cores were obtained during September 1991. Two backfill cores were collected from within approximately a 15-foot radius of the well at each of the three sites. Core holes ranged from 22.5 to 27.5 feet deep and were at least as deep as the associated well.

Ground-water samples were collected at each well in September, 1991 and July or August 1992. Wells were pumped at approximately 1.2 gallons per minute with a submersible, positive displacement pump until pH, specific conductance, and temperature were stable before samples were collected.

LABORATORY ANALYSES

Backfill Cores

Total elemental analyses of the 18 selected backfill core samples were completed. Results indicate total selenium concentrations in backfill core samples ranged from 0.1 to 15 mg/kg.

X-ray diffraction analyses indicated that the backfill core samples have similar types of mineralogy; quartz, kaolinite, potassium feldspar, illite, and muscovite were identified in all samples. Additional minerals that were detected in some samples include: gypsum, calcite, dolomite, apatite, and geothite. Total elemental analyses indicated that all backfill core samples were dominated by iron concentrations. X-ray diffraction analysis, however, did not show any peaks that are indicative of crystalline iron oxides. Inspection of the backfill core samples using

a microscope indicated the presence of a coating on selected clay particles in all backfill core samples that may have been an amorphous iron oxide.

Saturated paste extracts were prepared for 136 backfill core samples. The pH, specific conductance, and redox potential (Eh) were determined on the saturated pastes. Selenium, sulfate, and dissolved organic carbon (DOC) were determined on saturated paste extracts. Saturated paste pH values for backfill core samples were typically between 6.0 and 8.0. This is probably due to the buffering effect of carbonates, which were present in all samples. The saturated paste pH and Eh measurements for backfill core samples taken near the ground-water table were very similar to those obtained for the ground-water samples. The specific conductance of the saturated paste extracts (0.21 to 0.84 S m^{-1}) indicate a large salt content in the backfill core samples. Selenium concentrations in the saturated paste extracts ranged from 1 to 156 µg/kg.

Sequential partial dissolution techniques are being used to partition backfill selenium into functionally definable associations of selenium with solid phases of backfill material. The information obtained may help identify the phases associated with selenium and help pedict the extent of mobilization and immobilization in response to changes of the ground-water environment. The procedure extracts selenium into five fractions: soluble, ligand exchangeable, acid extractable, oxidative acid decomposable , and strong mixed-acid digestable. Sequential partial dissolution analyses are currently in progress.

Ground Water

Ground-water samples were analyzed for DOC, total selenium, major and trace elements. Total selenium concentrations in 1991 were found to parallel the DOC concentrations (79 to 88 mg/L). Ground-water samples A-1 and B-1, which had high DOC concentrations, had selenium concentrations of 125 µg/L (A-1) and 88 µg/L (B-1). Ground-water sample A-2, which had a low DOC concentration (11 to 14 mg/L, had a selenium concentration of 3 µg/L. DOC concentrations in ground-water samples collected in 1991 did not appear to be significantly different from those collected in 1992.

Dissolved Organic Carbon

DOC was fractionated into 6 DOC fractions: hydrophobic acids, bases and neutrals, and hydrophilic acids, bases, and neutrals. The results of the DOC fractionation analysis indicate DOC in the ground-water samples was dominated by organic acids (61 to 82 percent), with organic neutrals ranging from 13 to 38 percent, and organic bases ranging from 4 to 10 percent. Initial studies indicated hydrophobic bases were a small percentage (0 to 2 percent) of the total DOC, therefore, hydrophobic bases were omitted from further analyses.

The hydrophobic and hydrophilic acids in the ground-water samples were isolated and concentrated. Ground-water samples from A-1 and B-1 wells were used in the isolation procedure. Ground-water samples from well A-2 were not used for isolation due to low DOC concentration. The isolated fractions were used in the sorption/desorption studies to determine their effect on Se sorption.

Sorption/Desorption Studies

Sorption/desorption experiments were conducted for six backfill core samples. Results show that backfill core samples have a very large selenium sorption capacity. All samples sorbed more than 90 percent of the selenium added as selenite (except one with a pH of 6.7 that sorbed 75 percent). The pH of the samples examined ranged between 3.7 and 6.7. Although pH is a major factor in controlling sorption, the sorption capacity generally remained constant within the observed pH range except at pH 6.7. The selenium desorbed by phosphate was about 50% of the sorbed selenium; this decrease may be due to precipitation processes.

Precipitation/Dissolution Studies

Precipitation/dissolution experiments were conducted to determine the equilibrium conditions for backfill core samples. Twenty-five grams of backfill core sample were reacted with 75 ml of distilled-deionized water on a mechanical shaker for 1 to 28 days. After reacting for 1, 3, 7, 14, 21, and 28 days, sample suspensions were filtered under an argon atmosphere using a 0.45 μm filter. Clear extracts were divided into two subsamples. Analysis of the extracts for pH, Eh, DOC, selenium, and major and trace elements has been completed.

Controlled Redox Studies

To examine the effect of oxidation-reduction processes on selenium sorption/desorption and precipitation/dissolution reactions in mine backfill and associated ground water we have designed a redox controlling device (RCD) in which redox potential can be controlled. This unit consists of a sample chamber with platinum, pH, and reference electrodes connected to a pH/millivolt meter. The meter is connected to a relay, which controls redox potential (±10 milliVolts) and pH (±0.1 unit) in the reaction cell. The device was tested and calibrated for distilled-deionized water and soil samples. The device controlled redox potential from +500 to -500 milliVolts with an accuracy of ±15 milliVolts. Initial studies with pure selenium suggested that the RCD could be used to measure and quantify redox potential effects on selenium speciation.

SUMMARY

Three field sites were selected and sampled in reclaimed areas at two surface coal mines. Two backfill cores and two sets of ground-water samples have been collected from each field site. Analyses of ground-water samples indicate that total selenium concentrations ranged from 3 to 125 μg/L and DOC concentrations ranged from 11 to 88 mg/L. Fractionation of DOC in ground-water samples indicated predominance of organic acids (61 to 82 percent). Results from sorption/desorption experiments showed that backfill core samples sorbed 75 to more than 90 percent of the added selenium and approximately 50% of the sorbed selenium was removed by a subsequent phosphate extraction. Precipitation/dissolution experiments were conducted and chemical analysis of extracts is completed. A redox controlling device has been developed in which the effects of oxidation-reduction on selenium sorption/desorption and precipitation/dissolution reactions will be studied.

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

G.F. VANCE, R.N. PASCH, P.K. CARROLL, M.S. PAGE,
B.K. SCHLADWEILER, P. WANEK, S.E. WILLIAMS

Semi-Annual Project Report

for the

Abandoned Coal Mine Land Research Program

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

George F. Vance[2], Roger N. Pasch[1], P. Kim Carroll, Margaret Stacy Page[3], Brenda K. Schladweiler[2], Patsy Wanek[2], and Stephen E. Williams[2]

[1]Inter-Mountain Laboratories, Inc., Sheridan, Wyoming

[2]Department of Plant, Soil, and Insect Sciences, University of Wyoming

[3]Department of Environmental Quality - Land Quality Division, State of Wyoming

October 8, 1993

Relationship Between Soil Selenium Concentrations and Selenium Uptake by Vegetation on Surface Coal Mine Lands in Wyoming

Introduction

Selenium in the environment is an important issue to abandoned as well as active surface coal mine land reclamation. Overburden material that is brought to the surface during surface coal mining operations may have extractable selenium levels of 0.1 mg/kg or more, a level that has previously been identified as "unsuitable" for reclamation purposes in Wyoming. Surface mining may also affect soil/backfill selenium chemistry, which may influence soil-plant selenium relationships as well. This project is examining the relationship between soil/backfill and plant selenium concentrations in one abandoned and two surface coal mines in Wyoming.

Objectives

The main objective of this project is to evaluate soil/backfill and plant selenium relationships. The specific objectives of this study are to determine:

1) **What extraction procedures might be a better indicator of "soluble" (plant available) soil selenium?**

2) **What forms of selenium are present in seleniferous soil and backfill materials, and how are these related to plant uptake of selenium?**

3) **What impacts do chemical, physical and biological soil characteristics have on plant uptake of selenium?**

4) **How does selenium content of native and reclaimed plant species vary during a growing season?**

5) **What effect does soil depth have on plant uptake of selenium?**

6) **What selenium suitability limits should be recommended for backfill materials to be topsoiled and revegetated?**

Sites selected for this project include an abandoned coal mine and two active coal mines located in the Powder River Basin. The abandoned coal mine site is located north of Sheridan and the two active coal mines (Black Thunder (BT) and Coal Creek (CC)) are located south of Gillette. There are many advantages in involving active coal mines, because an extensive soil and backfill selenium data base already exists.

The relationship between soil/backfill selenium levels (determined from four different extraction methods and total selenium) and plant selenium levels (three different life forms - grass, forb, and shrub, as well as a composite grass sample which was a random collection of a mixture of grasses) is being examined. Information from both native (N) and reclaimed (R) areas located in active coal mines will be extrapolated to abandoned coal mine lands. The information obtained from this study will, in part, be used to better understand those conditions that influence selenium uptake in plants. This is an important issue to abandoned and active coal mine lands because it may indicate how overburden materials should be handled in the backfilling and reclamation process.

Methods of Analysis

Four selenium extraction methods (hot water selenium (HWSe), AB-DTPA selenium (ABCSe), KH_2PO_4 selenium (HPSe), and saturated paste selenium (SPSe)) and the analysis of total soil selenium (TSe), are being evaluated to determine which method(s) is the most reproducible and accurate for determining the effects of selenium uptake by plants (grass (G), forb (F), shrub(S), and composite grass (CG)). Plant selenium is being determined after plant digestion using nitric acid. A quality control/quality assurance program (see original proposal for details) was developed by the two laboratories, Inter-Mountain Laboratory, Sheridan, Wyoming and the Soil and Environmental Chemistry Laboratory at the University of Wyoming, that are conducting the soil and plant selenium analyses. Selenium analysis of both 1991 and 1992 vegetation and soil/backfill samples has been completed and the data downloaded into the University of Wyoming's mainframe computer.

Vegetation and Soil/Backfill Sampling

During the summer of 1993, both vegetation and soil/backfill materials were sampled. The plant and soil/backfill materials collected in 1993 have been processed and are currently being analyzed.

The following is a summary of the 1993 field sampling:

Sites Sampled: 12 BTN 45 BTR
9 CCN 6 CCR

Vegetation Sampling Times: early June and early August

Number of Plants Sampled: 671 total

144 BTN 368 BTR
102 CCN 57 CCR

Soil Sampling Period: early June

Number of Soil Samples: 752 total

159 BTN 375 BTR
166 CCN 52 CCR

Vegetation and soil/backfill materials collected from native and reclaimed research sites are currently being analyzed. Plant species inventories and determination of percent plant cover at each site were tabulated during the summer sampling periods. These will be compared to 1991 and 1992 data to determine if there were major changes in vegetation composition.

Results

Statistical correlation analyses were run on all dependent and independent variables. Significant variables, as identified by meaningful correlation coefficients, were identified using both extractable and total selenium concentrations as variables, and evaluating the relationship among soil/backfill selenium concentrations and plant selenium levels.

Correlations of significance among soil/backfill extractable and total selenium relationships were surveyed by mine (Black Thunder (BT) and Coal Creek (CC)), type of environment (native (N) and reclaimed (R)), and depth (five depths for native and three for reclaimed). In addition, different combinations were also evaluated (mine and type, type and depth, and mine, type and depth). Correlations of significance between soil/backfill selenium and vegetation lifeform selenium were also evaluated using the same type of comparisons as listed above.

Using a significance level of p=0.01 and a correlation coefficient of 0.9 or greater, several trends were found when comparing soil/backfill extractable and total selenium concentrations. When separating by mine **or** type, a consistent relationship was found, which indicated HWSe, ABCSe, and HPSe were all statistically correlated. Separation by mine **and** type, indicated ABCSe and HPSe were highly correlated in BTR, CCN, and CCR samples; all correlation coefficients for BTN were less than 0.9.

Including depth as a variable in the above examples resulted in several significant correlations; however, the only logical combinations are between type, and mine and type because mine, type, and depth combinations are meaningless since depths for native sites are by 30 cm increments and depths for reclaimed are by approximately 60 cm increments. With native sites, significant correlations were found for HWSe, ABCSe, and HPSe for all depths except depth 1 (top 30 cm of soil) which had correlation coefficients of 0.8. All reclaimed depths had HWSe, ABCSe, and HPSe that were significantly correlated. Separating by mine, type, and depth indicated there were significant correlations ($r \geq 0.9$) among HWSe, ABCSe, and HPSe at BTN5 (i.e., Black Thunder native depth 5), BTR2 and BTR3, CCN2 through CCN5, CCR2 and CCR3. For the remaining comparisons, correlations were either significant between two variables or were lower than 0.9; several correlations were found with correlation coefficients of 0.7 or 0.8.

Using a significance level of p=0.01 and a correlation coefficient of 0.5 or greater, several trends were found when comparing soil/backfill extractable and total selenium concentrations with vegetation lifeform selenium levels. Evaluations by mine **or** type indicated shrubs were the only lifeform that consistently correlated to ABCSe and HPSe. Both grasses and composite grasses were significantly correlated with HWSe and HPSe at both CC mine or on native sites. No significant correlations were found for forbs when mine **or** type was evaluated. When evaluating by mine and type, grasses, forbs, shrubs, and composite grasses were significantly correlated with HWSe, ABCSe, and HPSe at CCN; shrubs with ABCSe, HPSe at BTR; shrubs with SPSe at BTN; and forbs with all four extractable selenium levels at CCR (negative correlation).

All these comparisons were completed by evaluation of combined depths; thus, if a significant relationship existed between mine, type and depth, it would not be apparent from the above analysis. Native sites, together and separated by mine, had the most significant correlations between all vegetation lifeforms and HWSe, ABCSe, and HPSe at each depth. Significant correlations at reclaimed sites were somewhat variable; variation may be due to other variables, such as time of reclamation or site conditions, which have not been statistically evaluated yet.

The quality control/quality assurance program developed for this project indicated there was excellent agreement between 1991 and 1992 results from Inter-Mountain Laboratories and the Soil and Environmental Chemistry Laboratory at University of Wyoming. Results for AB-

DTPA, hot water, and phosphate extractable selenium exhibited linear regression correlation coefficients (r^2) of greater than 0.95.

Items to be completed

1) Laboratory analysis of 1993 soil and vegetation samples

2) All project data will be complied and used as a master data base for statistical evaluation. Correlations, linear and multiple regression, cluster analysis, and models will be examined or developed and tested through seasonal and yearly comparisons. Some example statistical evaluations that will be preformed are:

   a) 1991, 1992, and 1993, data will be statistically analyzed to determine what relationships exist between soil/backfill and plant selenium.

   b) Plant species, cumulative depth, and their relationship to the various extractants and resulting plant selenium will be evaluated.

   c) Significance of sampling soil/backfill at three holes at each site location will be determined.

3) A final report will be completed and submitted to the ACML research program.

Presentations and Publications:

Carroll, P.K., J.G. Luther, M.F. Raisbeck, L.K. Spackman, D.G. Steward, G.F. Vance and L.E. Vicklund. 1993. Selenium and Mining in the Powder River Basin, Wyoming. Billings Reclamation Symposium Proceedings Vol I:160-175.

Pasch, R.N. 1993. Producing an extractable selenium standard from spoil material for use as a control sample. Billings Reclamation Symposium Proceedings Vol I:131-138.

Schladweiler, B.K., G.F. Vance, R.N. Pasch, P.K. Carroll, M.S. Page, P. Wanek, D.L. Bonett, and S.E. Williams. 1993. Comparison of selenium uptake by vegetation on surface coal mine lands in Wyoming and seasonal variability of uptake. American Society of Surface Mining and Reclamation Vol. II:828-838.

Schladweiler, B.K., R.N. Pasch, G.F. Vance, P.K. Carroll, M.S. Page, D.L. Bonett and S.E. Williams. 1993. Relationship between soil selenium concentrations and selenium uptake by vegetation on surface coal mine lands in Wyoming. Billings Reclamation Symposium Proceedings Vol. I:119-130.

Steward, D.G., J.G. Luther, P.K. Carroll, L.E. Vicklund, G.F. Vance, and L.K. Spackman. 1993. Standard operating procedures for sampling selenium in vegetation. University of Wyoming College of Agriculture Miscellaneous Bulletin. (in progress)

Vance, G.F., R.N. Pasch, D.L. Bonett, B.K. Schladweiler, P.K. Carroll and M.S. Page. 1992. Evaluation of various selenium extraction methods for correlating soil/backfill levels to plant concentrations. Agronomy Abstracts, p.246.

THE INFLUENCE OF POST-HARVEST AND PREPLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. BOOTH, E.E. ROOS

NO PRESENTATION, FIELD WORK BEGINS FEB 1994

United States Department of Agriculture
Agricultural Research Service
Northern Plains Area
High Plains Grasslands Research Station
8408 Hildreth Road
Cheyenne, WY 82009
Comm: (307) 772-2433
FAX: (307) 637-6124

14 May 1993

To: Office of Research
University of Wyoming
Box 3355, University Station
Room 201, Old Main
Laramie, WY 82071-3355

From: D.T. Booth
USDA, Agricultural Research Service
High Plains Grasslands Research Station
8408 Hildreth Road
Cheyenne, WY 82009

RE: Brief outline of research plans for newly funded project "The influence of post-harvest and preplanting seed treatment on sagebrush seedling vigor," ACMLRP.

This project will be conducted by scientists of the High Plains Grasslands Research Station, Cheyenne, WY (ARS) and the National Seed Storage Laboratory, Fort Collins, CO (ARS), with the cooperation of Wind River Seed Co. (Manderson, WY). Wind River Seed will locate and collect seed from appropriate locations so seedlots tested will represent a range of ecotypes likely to be used by mining companies in this region. Because of the need to identify, collect, and do seed quality analysis, initiation of funded support for the project will begin 1 January 1994.

We will be testing post-harvest handling, humidification, imbibition, and germination / early growth for three ecotypes of big sagebrush. Specific research questions and the interaction of factors likely to influence seedling vigor are:

I. POST-HARVEST HANDLING

A. Questions:
1. Does drying sagebrush seed have a negative influence on germination or seedling vigor? If so, is this due to an increase in seed dormancy, or does drying damage the seedcoat?
2. Does exposure to heat (>50°C) during seed processing affect germination or seedling vigor?
3. Should the pericarp be retained during seed processing to protect the seed from desiccation - does it influence seed moisture?

B. Tests: These questions will be addressed in replicated laboratory germination and growth studies and will follow

studies monitoring temperature and humidity during seed processing.

II. HUMIDIFICATION

A. Questions:
   1. How does initial seed moisture influence seed humidification?
   2. What will be the pattern of weight gain over time?
   3. How do time and temperature influence total gain? Rate of gain?

B. Test: Humidification curves will be developed by weighing seed samples held over distilled water after the initial seed moisture has been determined. Tests will be conducted at 2 or more temperatures and 3 or more time periods.

III. IMBIBITION

A. Question: How do humidification treatments influence imbibition?

B. Tests: Imbibition curves showing water uptake over time will be developed at 3 imbibition temperatures for likely humidification conditions. These curves will be used to determine the average time needed for seed to reach Phase II imbibition.

IV. GERMINATION AND GROWTH

A. Questions: Are germination and post-germination seedling vigor (heterotrophic growth) influenced by the interaction of seed moisture and temperature during humidification, imbibition, and germination?

B. Test: Humidified seed will be imbibed until Phase II imbibition is reached, then transferred to the germination temperature. Germination will be counted daily. Seedling growth will be measured after 5, 7, and 10 days of incubation at the germination temperature. The growth measurements will be taken at these intervals to assure that all treatments are measured when they reach their maximum length and before seedlings begin to atrophy. It is not expected that the growth measurements will be indicative of growth in the field; rather, that they will serve as an index to relative seedling vigor among the seed treatments. Laboratory results will subsequently be retested in greenhouse and field studies.

V. FIELD TEST

A. Question: Will optimum seed handling make a real difference to mine reclamation?

B. Test: If laboratory and greenhouse tests indicate that improvements to post-harvest handling and/or using seed humidification will increase seedling vigor, then these

treatments will be tested in the field at Glenrock Coal Company's Dave Johnson Mine to determine if the treatments result in a greater number of seedlings at the end of the first growing season. Treated and non-treated sagebrush will be sown using the most current information and technology.